In Situ Pipeline Data Monitoring

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Abstract
It is now uncommon for a cemented paste backfill underground distribution system to not have some sort of pipeline instrumentation. The common types of instrumentation are pressure and flow meters. While these instruments are useful and can be used to both control and design the distribution system, it is hard to check the overall performance of the system with something external to the system.

This paper presents a case study using an *in situ* pipeline instrument called a Piper developed by INGU. This instrument is actually a small cluster of instruments that monitor pipeline pressure, acceleration, rotation, magnetic flux, and acoustic emissions. The Piper is used to measure the flow behaviour within the pipeline, as well as attempting to determine possible wear areas and determining potential leaks.

The case study area is the reticulation network at the Dead Bullock Soak Mine located at Newmont's Tanami Operations. The paper includes discussion trial setup and approach, including deployment and retrieval. It also provide an analysis of the Piper data in comparisons with the reticulation network instrumentation and the operational flow model. Piper data will also be tied into operational observations.

Key words: instrumentation, *in situ*, underground, backfill, reticulation, delivery, hydraulics

Introduction
Pipeline instrumentation is now common on the underground distribution systems (UDS) of underground (UG) cemented paste backfill reticulation networks. The most common instrumentation is pipeline pressure sensors, with a flow meter being the next most common. These sensors are useful for controlling the UDS as well as determining its performance and comparing this performance to design of the network. This is particularly useful if the trends of these instruments can be viewed in both real and historic time, as well as if the trends can be downloaded for further analysis. In terms of design to performance correlation and hydraulic model calibration, these instruments are important. However, there are other inputs that are also important, such as accurate reticulation geometries and rheological parameters.

There have been discrepancies between the hydraulic model and the pipeline instrumentation at Newmont's Tanami Operation's Dead Bullock Soak (DBS) mine. The pipeline pressure sensors were checked using an analogue pressure gauge and the instruments were found to be consistent. An additional flow meter was installed on the system and, when under full flow, these two sensors were consistent. Therefore, it was desired to use an external device to check the performance of the reticulation system. A Piper was trialed, developed by INGU (INGU, 2022). The Piper is a golf ball sized instrumentation package that can be sent through the pipeline and obtain data along its travels.

The INGU Piper consists of a spherical, hard plastic protective casing which encloses a suite of instruments: a magnetometer, an accelerometer, a gyroscope, an acoustic sensor, and a pressure sensor.

There are three types that can be used depending on the diameter of the pipeline. For this trial, the medium-sized Piper was used as this matched the DBS pipeline. A medium-sized Piper is shown in Figure 1 (for scale, the Piper is inside a 200 mm diameter pipe). INGU modified the DBS trial Pipers slightly by making them heavier than a stock item. This is due to a CPB slurry being significantly denser than water and oil with which INGU usually contends.

Figure 1. A Piper instrument cluster inside a 200 mm diameter pipe.

Conducting the Trial

Placing and removing a Piper were two major issues to be overcome. It was not possible to enter the UDS via the hopper as there was a pump located between the hopper and the top of the intended borehole. Even if a different borehole was used (meaning that the pump would not be required), it was also possible that the Piper would have trouble entering the UDS from the hopper. To this end a 'breach'-style loading valve spool was built on top of the borehole (Figure 2). When the knife gate valve was closed, the gate would prevent venting the UDS to atmosphere. The gate also allowed the Piper to be held inside the loading chamber (Figure 3). Once the top of the loading chamber was sealed with a plate, the knife gate valve could be opened to release the Piper into the UDS.

It was also important to be able to retrieve the Piper from the end of the UDS as the data needed to be obtained from the instrument. To this end a catcher was designed that could be fitted onto the end of the pipeline. One of the design features was that it could be flipped down once the Piper was in the system and then flipped back out of the way once the Piper was retrieved. There were a few design changes to the catcher throughout the trial.

Figure 2. A photograph showing the knife gate valve spool for launching the Piper into the UDS.

Figure 3. Images showing the catcher when delivered (left), when not engaged (middle), and engaged with CPB flowing (right).

The trial was delayed for several reasons, mainly COVID restrictions and the lack of an appropriate stope. Initially, a stope that was to be filled through a raise was desired as this would allow easier access to the catcher than a typical overcut-accessed stope. Unfortunately, this type of filling setup is rare. However, it was suggested that the trial be run into a dump zone on the 181L. This had advantages over a stope as it was not dependent on the mining schedule and could be setup outside of any schedule constraints. It also gave more flexibility on when to complete the trial and allowed much easier access to the catcher during the trial. Additionally, there was a pipeline pressure sensor just upstream of the dump zone. The disadvantage was that the size of the dump zone, even though it is the largest dump zone at DBS, meant that the plant was able to fill the dump zone in ~ 1 hour. This required getting the plant stabilized as quickly as possible to provide the best operating conditions possible.

Note that no specific CPB sampling or rheological test work was completed during the trial. This is unfortunate as it limits how the CPB characteristics can be linked to both the Piper and UG pipeline instrument results as well as the hydraulic model. All correlations between the Piper instrumentation and the DBS hydraulic model used the existing DBS laboratory test work database.

The UDS setup

The UDS instrumentation consisted of pipeline pressure sensors and flow meters; approximate locations are shown on Figure 4. The total length of the 181L dump zone UDS was approximately 2.6 km and dropped approximately 1.2 km in depth. The pipeline on the 181L was extended to improve the performance of the UDS.

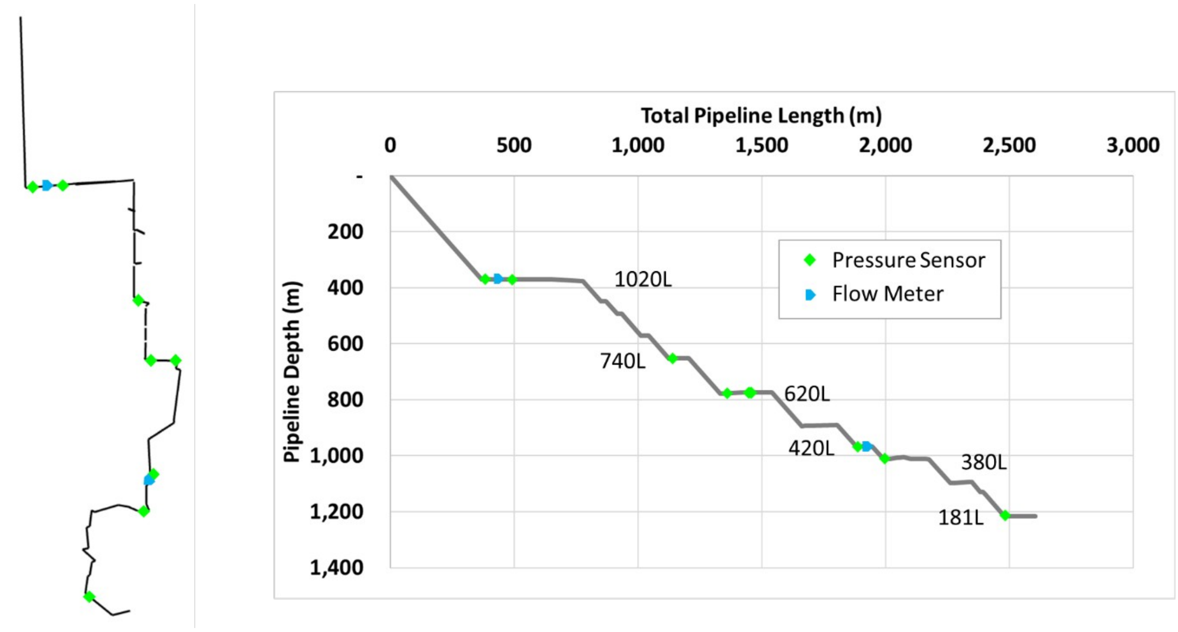

Figure 4. An isometric view of the 181L dump zone UDS setup (left side) and a 2D representation of this UDS geometry (right side).

Pipeline instrumentation data

The plant ran for just over an hour (~3:40–4:55). Based on the hydraulic model, it was estimated that it would take ~ 35 minutes for the CPB to reach the dump zone after leaving the plant. This estimate is reasonable given the pressure increase on the 181L pressure sensor around 4:11. Full flow at the 421L occurs at 4:05, as this is when the two flow meters start to mirror each other.

This UDS start up shows the typical behaviour albeit a bit truncated given the time constraints. The operator increased the plant's percent solids (increasing the density of the CPB) which drives the pipeline pressures higher. Around 3:53, the operator responded to the rapid pressure gain on the 1020 by decreasing the percent solids setpoint. This decrease in turn caused the flow to increase, which prompted another increase in percent solids. At this point, the system was starting to stabilize. Unfortunately, the dump zone was about full at this time. To this end, both trials were run when the system was more dynamic than ideal. However, this was always going to be an issue given the limited amount of run time into the 181L dump zone. UDS instrumentation data obtained from the trial period are shown in Figure 5.

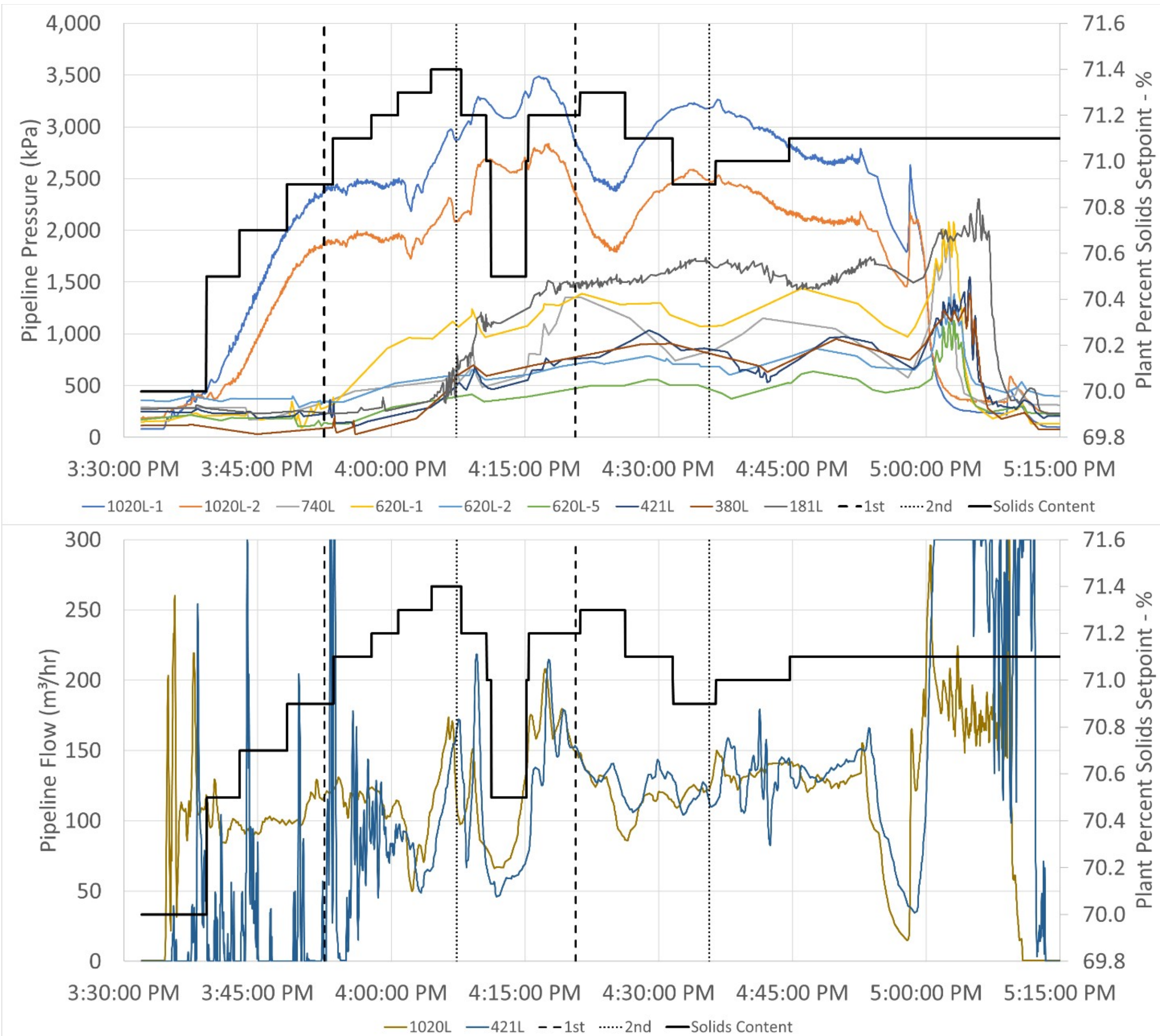

Figure 5. Plots showing the pipeline instrumentation obtained over the 181L dump zone trial period. The upper plot contains the pipeline pressure instrumentation data and the lower plot contains the flow meter data; the plant's percent solids setpoint is also shown on both secondary axes. There were two Piper runs and their run times are also shown: large black dashes for the first run (~3:52 to ~4:21) and black dots for the second run (~4:07 to ~4:36).

Analysis
This section concentrates on the data obtained from the Piper trials and how these data fits with the UG pipeline instruments and the hydraulic model (INGU, 2022). To this end, it will focus primarily on comparing the pipeline instrumentation to the corresponding Piper instrumentation.

Pipeline pressures, accelerometer, and the gyroscope
There were some interesting results (Figure 6). The first was that there is approximately 100 m of freefall in the surface delivery borehole when the 1st Piper was deployed while surface delivery borehole was full when the 2nd Piper was deployed.

Figure 6 also shows areas of 'slack flow'. Slack flow occurs where there is no (or slightly negative) pipeline pressure, meaning that the pipeline is not running full. Pipeline sections around a slack flow area are usually also high maintenance areas due elevated wear and damage-inducing vibrations. Slack flow, in an UDS, usually occurs at the top of a borehole after relatively long horizontal run. Both Piper trends shows this, particularly well in the first run. Additionally, this plot shows that slack flow areas decrease or are prevented as the density of the CBP is increased.

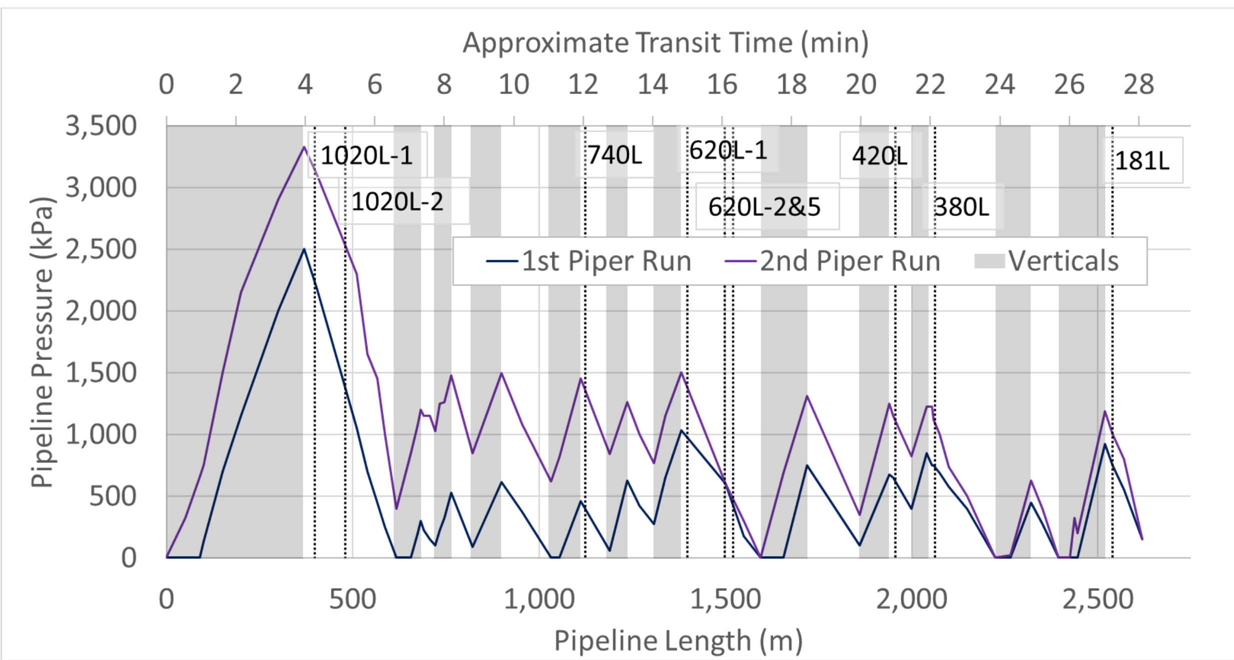

Figure 6. The two pressure profiles generated from the first and second Piper runs, where shaded grey areas indicate regions of vertically-oriented pipe (as determined from Piper data). The difference between the two runs is the density of the paste; the first run had an overall lower density CPB than the second run.

Plots in Figure 7 compare the pressures from the pipeline pressure instrumentation (line trends) with the Piper instrumentation taken at approximately the same time as the Piper passed each pipeline instrument (obtained from Figure 6 and shown by coloured markers). Both plots, particularly the second run, show good correlation between the Piper and the pipeline instrumentation results. Specifically, the 1020L and 620L pressures agree well. However, the 181L pressures are different in both runs, with the Piper pressures being significantly less than the 181L pipeline sensor.

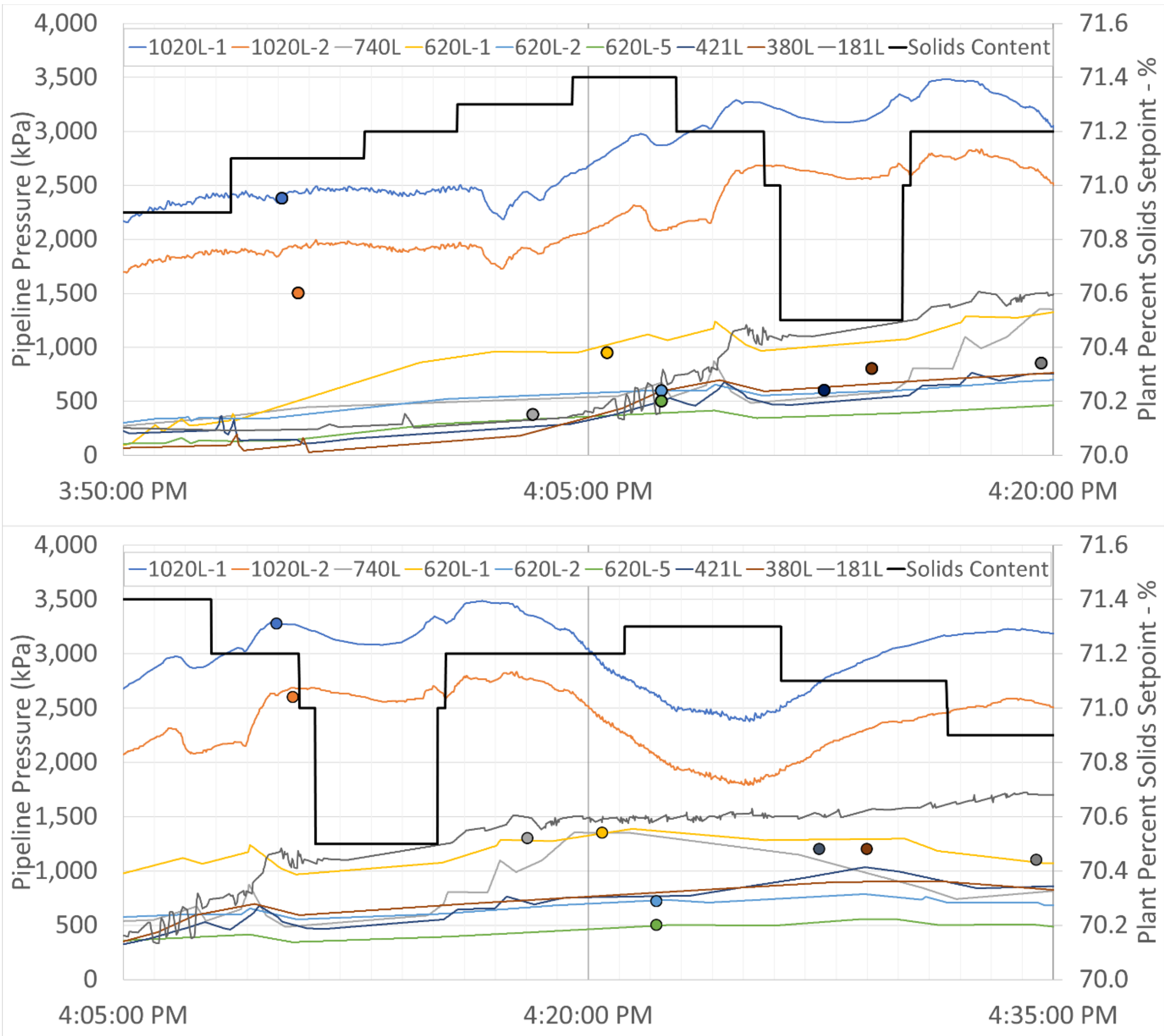

Figure 7. Comparison plots of the Piper and the pipeline instrumentation pressure results. The Piper pressures are shown as coloured markers that correspond to the pipeline instrument. These pressures were obtained at the approximate time the Piper passed the pipeline instrument. The upper plot is for the first run and the lower plot is for the second run.

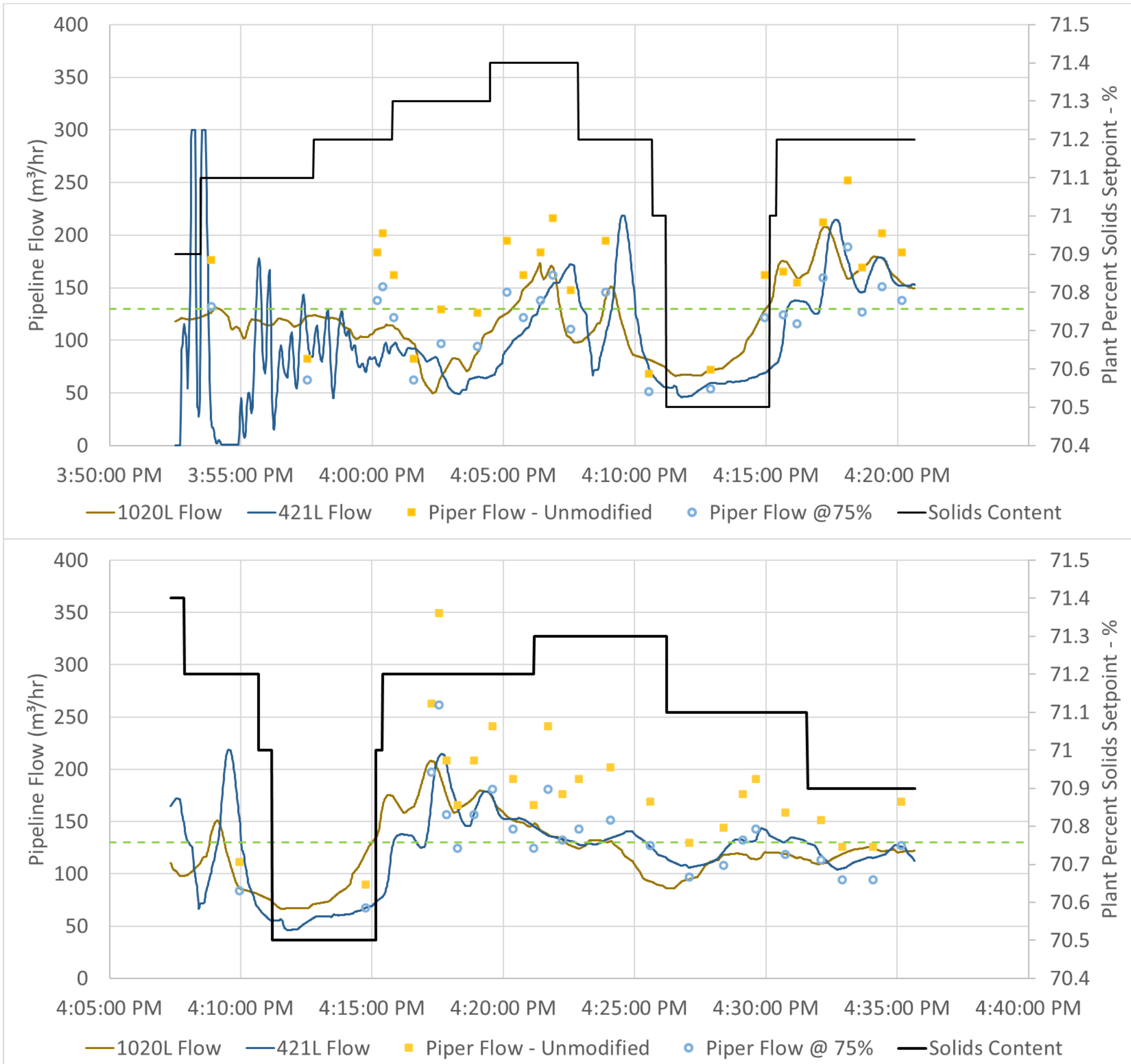

Figure 8. Comparison plots of the Piper flow versus the pipeline flow instrumentation; upper plot is for the first run and the lower plot is for the second run, and yellow markers show the Piper data while tan and blue lines show the 1020L and 421L flowmeter data, respectively.

A comparison of these data show that Piper results are higher than the UG instrumentation results but both data sets have the same trends. Decreasing Piper results by 25% allowed for a better match between the Piper and UG results. For reference, the CPB plant's throughput was set at a 130 m^3/hr (dashed green line) throughout the trial. This discrepancy is likely due to how the Piper velocity values are converted to flow. Flow is usually calculated by multiplying CPB velocity by pipe interior cross-sectional area. This would be valid for areas that are in full-pipe laminar flow, but there are areas within the UDS where this was not the case.

Calibration of hydraulic model to pipeline and *in situ* instrumentation results

As mentioned previously, the major focus of the Piper trial was to have an independent check of the performance of the DBS reticulation model. Figure 9 contains compares the DBS hydraulic model pressure profile with the results of the two Piper models (same pressure profiles given in Figure 6). The DBS hydraulic model results were created by correlating the model output with the average pipeline pressure results.

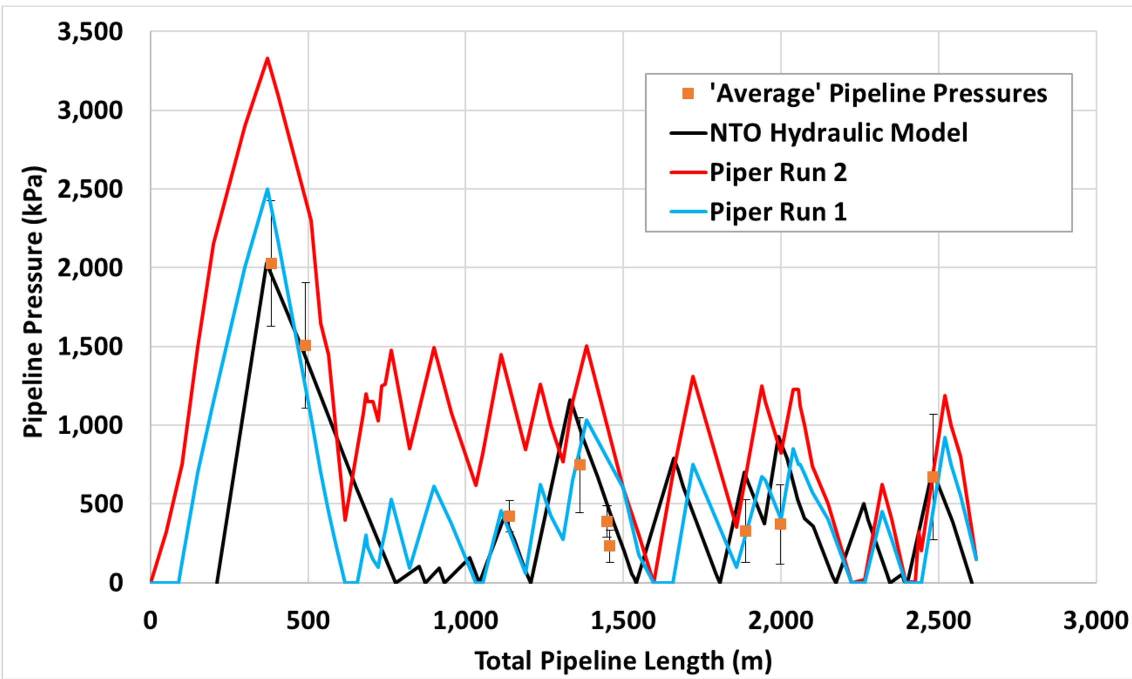

Figure 9. Comparison plot of the pressure profiles measured during the two piper runs (also shown in Figure 6) and the pressure profile determined from the DBS hydraulic model.

A comparison of the general pipeline geometries shows a couple of readily apparent discrepancies. The first is that the model's 1020L length is approximately 200 m longer than it should be. The model is also missing a 60 m backbone extension loop on the 700L. There were also some other minor tweaks made to the lengths of several levels. Length-calibrated model results are shown in Figure 10. Three different density CPB models were used to attempt to match the Piper trials; it is difficult to match the model to the Piper pressure profiles despite the geometry calibration. It is expected that this is due to the dynamic nature of the actual system and that the model is steady state.

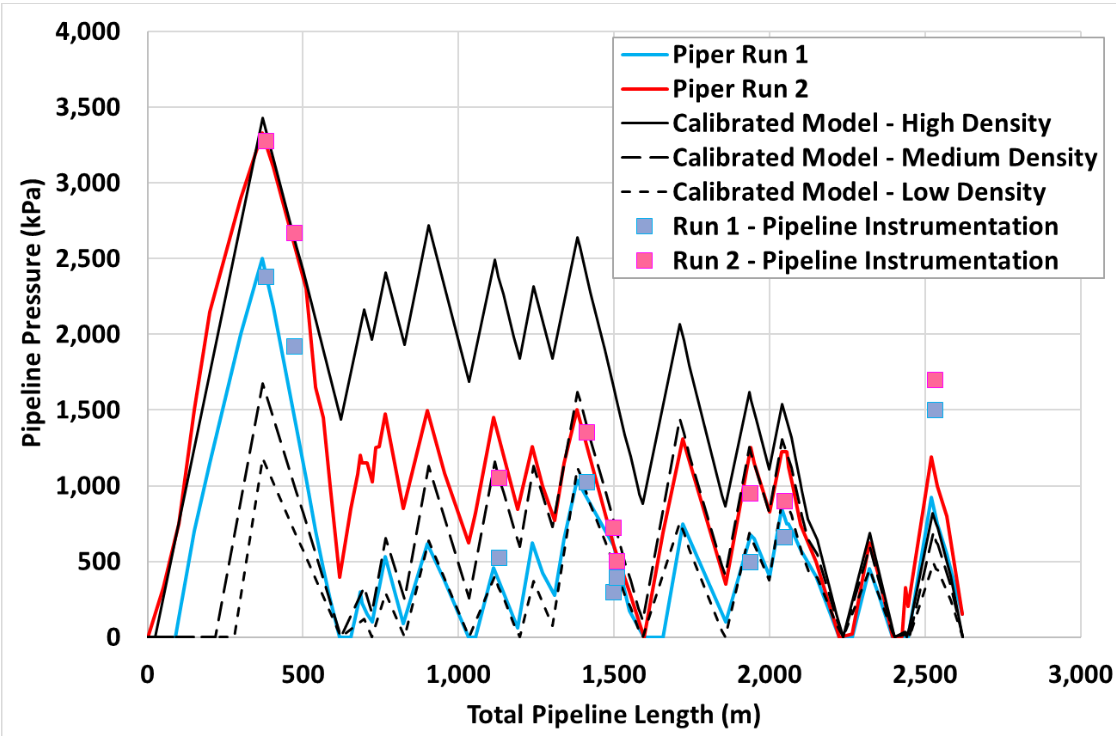

Figure 10. Pressure profiles measured during the two Piper runs, three pressure profiles simulations (high, medium, low density CPB) developed by the calibrated DBS reticulation model, and the UG pipeline pressure readings (taken from Figure 7).

Acoustic emissions

The acoustic emission sensor data analysis works by comparing the average background noise to any louder, anomalous point noise sources. The locations of these point sources can then be investigated for leaks. In general, it was found that the DBS system was noisier than expected, particularly in the areas that were experiencing slack flow. Additionally, given that the slack flow areas changed between the runs, it was hard to difficult to compare the runs' acoustic results. During the first run, the sensor did pick up some acoustic signatures that had some characteristics of a leak at approximately 280 m depth in the surface delivery borehole. However, no signatures were recorded on the second run at the same location, which suggests that a different mechanism may have caused the acoustic emission in the first run.

Magnetic flux

The magnetic flux sensor was able to pick up a lot of variations within the system. Again, results obtained were noisier than expected. Note that this survey was only conducted on the first Piper run as this was a trial to see how it performed.

This sort of survey works better as a comparison so discrepancies can be highlighted between runs (similar to wear monitoring surveys). However, magnetic flux was able to differentiate the following:

- changes between vertical and lateral sections, partially due to changes in pipeline orientation and thickness
- different pipe joint connections (welds, threaded couplings, or Victaulic couplings) generally had different signatures
- the levels were noisier than the verticals, ie, extensively braced levels (eg. 900L, 940L, 380L) were noisier than less braced levels (eg, 820L, 420L)
- there were spikes associated with various pipeline fixtures at level entrances and exits attributed to borehole breastplates, at locations that corresponded to diversion and dump valves, and from magnetic flow meters
- differences between the steel pipe and the ~ 40 m of HDPE at the end of the pipe, where HPDE has a very different signature relative to the steel pipe

Conclusions

The main focus of the Piper trial was to provide an independent performance check on both the performance of the DBS UDS and the hydraulic model. A secondary focus was to see how other instruments within the Piper worked in a backfill UDS. The trial was run into a dump zone on the 181L. While this was advantageous from an operational perspective, it did limit the trial as the plant could only run for about an hour before the dump zone was filled. Due to this, the performance of the CPF system was a more dynamic than ideal. It would be recommended that trials be run to voids that would allow for longer running times.

Despite these limitations, the Piper trial was very useful. A comparison of the Piper and UG instrumentation showed similar results, where:

- pipeline and Piper pressures were generally similar
- the Pipers were able to identify areas of slack flow and how these areas changed with increased CPF density
- flow data showed similar trends on comparison, but with Pipers reporting higher flows than the UG instrumentation

The Piper data were most useful in calibrating the DBS hydraulic model. Data highlighted a couple of large geometric discrepancies, mainly an incorrect length of the 1020L and a missing extension loop on the 700L. Additionally, Piper trial data will be used to inform further reticulation model upgrades.

Acoustic emission data were inconclusive, mainly as the system was noisier than expected. It is anticipated that this sensor could provide better results if the system was stable. Magnetic flux data showed a lot of potential and, depending on the level of effort investment in which an operation is interested, could be used to determine exactly where different types of pipeline hardware were installed and how the system changes with time. However, to utilize fully this potential, multiple runs would be required to establish how the UDS changes from its baseline measurements.

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